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Intense geomagnetic storms with Ap $\geq$ 100 during 21-23 sunspot solar cycles

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Based on the monthly data of various parameters e.g. sunspot numbers (SSNs). Solar Flares, planetary index (Ap) with intense geomagnetic storms (GMSs) for the last two sunspot solar Cycles (21,22) as well as for the present cycle 23 (up to 2000) a detailed statistical study has been performed. Thirty Two intense GMSs with $A_p \geq 100$ have been identified during above said period 50% intense geomagnetic storms have occurred during maximum activity period of 22nd sunspot cycle. This trend is not observed during 21st, 23rd Sunspot cycles. 68.7% intense GMSs are caused by coronal mass ejections and shocks that they produce. 37.5% GMSs are associated with shock plus ejecta where as 16% are related with shock without ejecta events. Statistically, it is observed that the transit time of solar event from the sun to near earth space fall in between 23.5 to 96.3 hours. Minimum and Maximum shock velocity has been found to be 435 Km/Sec. and 1700 Km/ Sec. respectively during the period of study.

1. Introduction

Since the beginning of the space age, the cause of geomagnetic activity has been sought in a number of correlative studies (Akasofu, 1983). It is suggested that geomagnetic, activity is related to variety of interplanetary plasma/field parameters: Solar wind velocity V. interplanetary magnetic field (IMF) B, IMF (Bz). (Gonzalez et al, 1989, Sabbah, 2000). Strong geomagnetic disturbance is associated with passage of magnetic cloud (Zhang and Burlaga, 1988; Gonzalez et al., 1994), which causes geomagnetic storms. It is known that interaction between slow and fast solar wind originating from coronal holes leads to create co rotating interaction region (CIR). Geomagnetic disturbances are generally represented by geomagnetic storms and sudden ionospheric disturbances (SIDs) Geomagnetic storms are also caused by interplanetary (IP) shocks or stream interfaces associated with high speed solar wind streams (HSSWS) (Howard et al., 1985. Webb and Howard, 1994). These are associated with Coronal holes, which occur in Polar Regions or higher latitude. Fast CME produce transient IP shocks, which cause storm sudden commencement at earth. Geomagnetic storms are associated with isolated disappearing filaments (Joselyn and McIntosh, 1981). The occurrence of prominences and flares are also associated with varying phases of sunspot cycle leading to the geomagnetic storms. The strength of IMF and its fluctuations have also shown to be most important parameter affecting the geomagnetic field conditions (Gonzalez et at., 1989). IMF directed south, allows sufficient energy transfer from the solar wind into the Earth magnetosphere through magnetic reconnection. Also this general idea of the solar cause of geomagnetic storms has been established for decades, the exact solar sources and their characteristics have not been well identified and studied until the advent of solar and heliospheric observatory (SOHO) spacecraft observations in 1996. Over half past century, it is thought that the solar flares are responsible for major (IP) particle events and SSCs (Garcia and Dryer, 1987). Recently, it is being observed that CMEs without considering solar flares are the key causal link with solar activity and produce GMSs. Data available from Skylab mission suggest that the coronal holes, CMEs, eruptive prominences and disappearing filaments have causal link with solar activity and they produce GMSs.

2. Data Analysis

In the 23 yr period from Jan 1977 to Dec. 2000, 32 intense geomagnetic storms have been observed on the planetary index Ap. Ap index, sunspot numbers (SSNs) derived from solar geophysical data reports. A geomagnetic storm is classified as an intense, if the index at the peak time is greater than 100 (Garcia and Dryer, 1987). To identify the solar sources of these intense geomagnetic storms, we make use of situ solar wind plasma, magnetic field, and particle data upto 1995. We used large scale and spectrometric coronagraph (LASCO) and the EUV imaging telescope (EIT) observations from 1996 to the end of the study, because LASCO and EIT have started in 1996 Jan. SSCs were obtained from solar geophysical data Statistical studies shows the time interval between the origination of solar events from the sun and near earth space is lying between 1 to 6 days and mainly depends upon the initial speed of ejecta (Hewish and Bravo, 1986; Gopalswami et al., 2000; Cane et al., 2000). This paper is intended to unambiguously identify solar sources of intense geomagnetic storms occurring between 1977 to 2000.

3. Result and Discussion

We have investigated 32 intense geomagnetic storms with Ap$\geq$ 100 and identify their possible reliable association with solar features as shown in table-1. Association with a solar event is assigned on the basis of the onset time and intensity time profiles of the low energy particle. The time (Hα maximum) and the position are from the group listings in SGD. Often it is not possible to define the onset time precisely, and it may also vary up to 8 hours (occasionally longer) between stations at different longitudes (Fenton et al., 1959; Lockwood, 1971). In this table first two column a, b indicate date and time of SSC. Columns c, d and e indicate the date, time and location of associated solar events. The class indicates the solar wind structures inferred to cause intense geomagnetic storms. The shock transit speed is determined from the time interval between solar event and associated SSCs. Last three columns f, g and h represents the class, shock velocity and kind of flow pattern of disturbances causing intense GMSs. In the class A, B, C and D represent that shock plus ejecta, shock without ejecta, strong shock and shock plus ejecta (less energetic) respectively. Solar wind data indicates the types of flow present with situ solar wind data. The designation ------- means there were insufficient data. Flow pattern 1/3, 2, 4 and TD indicates transient flow plus ejecta, transient flow (no ejecta), complex flow/ high-speed streams and transient disturbance respectively. It is observed that 50% geomagnetic storms have occurred during maximum activity of 22nd sunspot cycle. These trends are not observed during 21st and 23rd sunspot cycle. This shows that this may be a coincidence. Some intense GMSs are associated with unique front side Halo CMEs while some are associated with multiple CMEs. For examples, the storm of 04 May 1998, which occurred at 0500 UT, is associated with multiple CME1, CME2, CME3. Date, UT, velocity and transit time of CME1, CME2, CME3, are 1,2, 2 May 1998, 2340, 0531, 1406, 632 Km/Sec 452 Km/Sec, 1044 Km/Sec and 5044, 36 hours respectively. The angular width (deg), source and coordinates of CME1, 2,3, are 360^0, 360^0,360^0, AR 2810, AR 2810, AR 2810 and S 18 W 05, S 20, W07, S15 W15 respectively. It is noticed that 12,05, 05, 03 intense geomagnetic storms are associated with class, A, B, C, and D respectively. From this, we conclude that 37.5 % of events causing geomagnetic storms are related with class A (Howard et al., 1985 Cane et al., 1996). 09, 05, 01 and 01 disturbances associated with transient flow plus ejecta, transient disturbances, transient flow without ejecta, and complex flow/ high speed streams respectively (Cane et al., 1996), while the flow pattern of 16 events are unknown due to insufficient of data. From this, we conclude that 48 events have transient flow pattern (Cane et al., 1985; 1996). The flow patterns of 50% events are unknown. Class A, B, C events are associated with CMEs causing intense geomagnetic storms (Gosling et al., 1999; Tsurutani & Gonzalez, 1998). Thus, we conclude that 68.7% events are associated with CMEs causing intense geomagnetic storms (Cane et al., 1996; Webb, et al., 2000; Zhang et al., 2003). One final aspect of this study is the provision of a list of solar wind disturbances causing SSCs which are well associated with solar events. Many researchers have attempted to learn about solar wind disturbances by making associations with solar events. However, some of these studies have not considered energetic particle data and as a result, some of these associations may be incorrect. As for example, Bothmer (1993) and Rust (1994) have attempted to relate the rotation of magnetic field in magnetic clouds with the twist of the magnetic field in particular prominence eruptions at the sun. Clearly, the conclusions of such studies will be more reliable if the associations have a higher probability of being correct. This result will be useful in determining the solar sources of geomagnetic storms (Zhang et al., 2003).

4. Conclusions

1. 50% intense geomagnetic storms have occurred during maximum activity period of 22nd sunspot cycle. This trend is not observed during 21st, 23rd Sunspot cycles.
2. 68.7% intense geomagnetic storms are caused by coronal mass ejections and shocks that they produce. This result is consistent with cane et al., 1996, Zhang et al., 2003 and inconsistent with Garcia and Dryer, 1987.
3. 37.5% GMSs are associated with shock plus ejecta where as 16% are related with shock without ejecta events.
4. 48% events causing GMSs are associated with transient flow pattern, where as the flow pattern of 50% events are uncertain (in sufficient data) producing interplanetary, shocks that can lead the occurrence of GMSs.
5. Statistically, it is observed that the transit time of solar from the sun to near earth space fall in between 23.5 hours to 96.3 hours. Further more, it is not always necessary that CMEs related events are associated with high-speed solar wind streams.

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Table 1: List of 32 intense Geomagnetic Storms

Date and time of SSC		Solar Event			Class	V_{sh} (Km/sec)	Kind of flow
A	b	c	d	e	f	g	h
Date	UT	Date	UT	Location			
12.04.81	1418	13.04.81	1100	N11 E43	C	435	--
12.07.82	0500	09.07.82	0825	N18 E76	B	830	TD
06.08.82	1840	--	--	--	--	--	--
05.09.82	2255	04.09.82	0200	N22 E29	C	940	TD
21.09.82	0345				C		TD
04.02.83	1616	03.02.83	0543	S17 W07	C	1220	TD
25.04.84	724	25.04.84	0001	S11 E45	B	1070	--
20.04.85	0712	--	--	--	--	--	1/3
06.02.86	1310	04.02.86	0741	S03 E21	C	936	4

12.03.89	0800	10.03.89	1850	N32 E22	A	750	--
15.03.89	0532	--	--	--	--	--	--
20.10.89	1900	19.10.89	1239	S25 E09	A	1470	1/3
17.11.89	0925	--	--	--	--	--	--
09.04.90	0844	--	--	--	D	--	--
28.07.90	0331	25.07.90	2232	S14 E56	B	790	--
23.03.91	0000	23.03.91	0311	S21 E13	A	1700	--
04.06.91	0337	--	--	--	B	--	2
09.06.91	0039	04.06.91	0037	N34 E75	B	620	--
14.06.91	0400	11.06.91	0108	N32 W15	A	1260	TD
01.11.91	0500	30.10.91	0613	S09 W26	A	1000	1/3
08.11.91	0647	--	--	--	D	--	--
08.07.91	1626	07.07.91	0208	N28 E01	A	1100	1/3
12.07.91	0923	10.07.91	1220	S22 E35	A	930	--
28.10.91	1100	27.10.91	0545	S13 E17	A	1420	1/3
09.05.92	1557	08.05.92	1530	S25 E07	A	1460	1/3
16.04.94	2108	--	--	--	D	690	--
06.04.95	1900	--	--	--	--	--	--
04.05.98	0500	01.05.98	2340	S18 E05	A	632	1/3
26.08.98	0653	--	--	--	--	--	--
24.09.98	2243	--	--	--	--	--	--
15.07.2000	2100	14.07.2000	1054	N22 W07	A	1674	1/3
29.11.2000	1300	26.11.2000	1706	N18 W38	A	980	1/3

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